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Nano - Prosthodontics: Beginning of a New Era

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Abstract

Science is presently undergoing a great evolution, taking humanity to a new era: the era of Nanotechnology with developments in material science, nanotechnology is especially anticipated to provide advances in dentistry and innovations in oral health-related diagnostic and therapeutic methods.Many authors published review articles discussing the potential of nanotechnology in Prosthodontics including newly developed materials. However, the literature is void of reviews addressing the science behind nanotechnology in detail and linking it to the implications nanotechnology. This literature review explains about the various purposes of nanotechnology and the science behind it, with its implications and challenges in Prosthodontics.

Keywords

Nanodentistry, Nano materials, Nano particles

Introduction

Science is presently undergoing a great evolution, taking humanity to a new era: the era of Nanotechnology[1]. The revolutionary development of nanotechnology has become the most highly energized discipline in science and technology[2]. It is a phenomenon present since the late 1950's and is currently finding a strong ground in the field of dentistry. The word "nano" which is derived from the Greek word (nannos) meaning "dwarf", is a prefix that literally refers to 1 billionth of a physical size[1].The term 'Nanotechnology' was coined by Prof. Kerie E. Drexler, a lecturer, researcher, and writer of Nanotechnology[1]. According to the definition of

National Nanotechnology Initiative, Nanotechnology is the direct manipulation of materials at the nanoscale[3]. This term defines a technology that enables almost complete control of the structure of matter at nano scale dimensions. Nanotechnology will give us the ability to arrange atoms and achieve effective, complete control of the structure of matter[4,5] .The use of this technology will allow many developments in the health sciences as well as in material science, bio-technology, electronic and computer technology, aviation, and space exploration. With developments in material science, nanotechnology is especially anticipated to provide advances in dentistry and innovations in oral health-related diagnostic and therapeutic methods.

In recent years, Nanomaterials have captured more and more attention because of their unique structures and properties. Nanomaterials can be divided in to four categories of nanopowder, nanofiber, nano membrane, and nano block, in which development of nanopowder is longest, and its technology is most mature[6]. Nano materials have small size, large surface area, high surface energy, a large proportion of surface atoms, and four unique effects: small size effect, quantum size effect, Quantum tunneling effect, and surface effect[2]. development of nanomaterials has greatly enriched the field of research in material science including biomaterials[6,7.] It made major changes that skyrocketed the possibilities to wield the power and control of diseases and extend the understanding of pathogenesis and identify the most microscopic and decisive step in the process and target it for cure and drug delivery which again will be through the use of nanotechnology (nanotherapy).

Due to the growing technologies and interest nanotechnology is used in dental applications and there is an emergence of a completely new stream that is known as nanodentistry. Nano dentistry helps in attaining good oral health while using nanomaterials and various biotechnologies like nano robots and tissue engineering etc. In dentistry, there are other treatment modalities where nanotechnology proves to be effective, and those include nano robots, nano needles, nano robotic dentrifices, bone replacement materials, nano composites, etc. Many authors published review articles discussing the potential of nanotechnology in Prosthodontics including newly developed materials. However, the literature is void of reviews addressing the science behind nanotechnology in detail and linking it to the implications nanotechnology[8,9]. This literature review explains about the various purpose of nanotechnology and the science behind it, with its implications and challenges in Prosthodontics. (FIGURE 1)

Nano Technology

Nanotechnology also known as molecular nanotechnology or molecular engineering, which produces functional materials and structures ranges between 0.1 and 100 nanometers. The properties of material can be modified just by manipulating the way of atoms or molecules are arranged. For example Graphite and diamond were made of carbon atoms with distinct properties, but the carbon atoms can bond together at the nanoscale in both. It explains the importance of nanotechnology. There are different approaches in the production of nanoproducts with this technology. The most common approaches include bottom up approach, top down and functional approach.

Bottom up approach

Methods used for producing nanoscale structure, through this method nanoparticles are produced directly.

Top down approach

Used to manufacture Nano scale structures. Mostly extension of method already employed in small scale, this is further miniaturization.

Functional approach

Components of a desired functionality are developed without regard to how they might be assembled.[10] (FIGURE 2)

Other approaches followed at Rice university (comprehensive research university, texas)are wet, dry and computational nanotechnology.

Wet nanotechnology

Study of biological system that exist mainly in water environment, which include genetic material, membranes, enzymes, and nano-sized cellular components.

Dry nanotechnology

It derives from surface science and physical chemistry focuses on fabrication of structure in carbon, silicon andother organic materials.

Computational nanotechnology

It permits the modeling and stimulation of complex nanometer scale structure, the predictive and analytical power of computation is critical to success in nanotechnology.

Nanotechnology is multidisciplinary, with its potential benefits it can be applied applied in science which includes medicine and dentistry[1].

Nano Biomaterials

The combination of nanotechnology and biomaterials was known as nanobiomaterials. These materials provided great opportunities to improve the preclusion, diagnosis, and treatment foroverall health diseases. Nanobiomaterials can be defined as a special category of biomaterials with constituent or surface sizes not more than 100 nm. [11]

Firstly, nanomaterials have much larger specific surface area when compared to their conventional forms, which was beneficial to obtain materials with greater biochemical reaction. Secondly, the mechanical properties were enhanced because of the hinging mechanisms, their chemistry such as grain boundary sliding and short-range diffusion healing. Thirdly, the nanostructure can lead to novel optical, electrical, and magnetic properties for materials due to their quantum effects which played a prior role in determining the properties and characteristics in nanoscale. In addition, the homogeneousness and purity in ingredient and structure were improved due to reaction or mixture at the molecular and atomic levels. At last, it was possible to modify the surface properties of nanostructured materials through advanced techniques.

Although nanobiomaterials have been applied to many aspects of medical and dental fields, the accurate interface interaction between cells/tissues and materials was not completely clear. Currently, researches on nanobiomaterials have entered a more comprehensive and systematic stage. The researchers are seeking further understanding of the mechanism behind the biological response to biomaterials and better design of such materials. Thus, the deep understanding of the interaction between nanobiomaterial surface and cells is the key to clinical application of nanobiomaterials.

Nano Dentistry

In the year 2000, the term and the field of nanodentistry were born. As nanomedicine advanced,

dentistry also started evolving in the field of Nanotechnology. Nanodentistry was defined as the science and technology that will make possible the maintenance of comprehensive oral health by means of nanomaterials, biotechnology including tissue engineering and ultimately dental nanorobotics.

Nano dentistry as bottom up approach: includes local anesthesia, hypersensitivity cure, nanorobotic dentrifices, dental durability and cosmetics, orthodontic treatment, photosensitizers and carriers, diagnosis of oral cancer and treatment of oral cancer.

Nano dentistry as top down approach: includes nanocomposites, nanosolution, nanoencapsulation, impression materials, nanoneedles and bone replacement material.

These exciting new branches namely nanorobotics, nanodiagnosis, nanomaterials, and nanosurgery and nanodrugs would profoundly impact clinical dentistry in the not-so-distant future.[12]

Nano Prosthodontics

Nanomaterials have been developed promptly and some researches of nanomaterials have been carried out on prosthodontics. Many of the current dental materials are available through nano crystallization performance. It plays a key role in the oral applications. Research of nanotechnology in dental materials is mainly focused on two ways: one is the preparation of new inorganic nanoparticles, and the other is to modify with inorganic nanofillers. [13,14]

Acrylic resin

The purpose of acrylic resin in dentistry ranges wide. It can be used for the fabrication of temporary base materials, temporary prosthesis, dentures(complete and partial) and orthodontic removable appliances(retainers and functional). PMMA resin denture base material has poor surface properties, weak mechanical properties including impact and flexural strengths with limited antimicrobial activity.[15]The modulus, strength, ductility, antimicrobial properties and aesthetic properties of PMMA have been improved by the addition of nanoparticles. Since nanoparticles are characterized by their small size, large surface area and intense interface interactions with the polymer matrix. These nanoparticles can enhance the physical and optical properties of the polymer matrix. In addition, they can provide resistance to environmental stress, cracking and aging.[15]

Titanium dioxide nanoparticles

have been incorporated due to its prominent catalytic effect, white colour, low toxicity, high stability, efficiency and availability of the material. In recent studies proved that it can be effective against[15]when its been incorporated in to acrylic resins. It also enhanced the mechanical properties of acrylic resins.

Silver nanoparticles

Silver (Ag) has been well known for its antimicrobial properties and it had a long history of application in medicine with well-tolerated tissue response and low toxicity profile. Particularly, silver nanoparticles which are the nanosized (nm) inorganic particle form of Ag, because of rapid and broad-spectrum efficacy and sustained release of silver cation (Ag^+) appear to be more effective means of prophylaxis than microsized. It is very significant when silver nanoparticles concentration above 80 ppm and at higher concentration it can leads to cytotoxicity. Kvetik[16] suggested that silver nanoparticles having the diameter of 25 nm caused death of the human fibroblast at the concentration higher than 60mg/L. If

the concentration of silver nanoparticles is maintained doesn't cause any consequences. These results suggested that composites with concentration to 40ppm of silver nanoparticles should be safe in oral cavity. And Douglas Roberto Monterio[17] suggested that with increase in silver nano particle incorporation there is a decrease in the mechanical properties of acrylic resin.

Zirconium oxide (Zro_2) nanoparticles

By incorporating nanozirconia in to auto polymerized repair resin it enhances the transverse strength of denture base material. Along with that it has good distribution property thereby it can enter and fill the spaces between polymeric chains which resulted in increased interfacial shear strength between the nanoparticles and polymeric chains and it can acts as contributing factor in improving the transverse strength. [18]

Carbon fiber/graphite reinforced

It increases the flexural strength and fracture toughness of denture base materials. It reinforces PMMA matrix prior to crack initiation; to arrest/retard early phase of crack propagation. However, an important clinical problem related to carbon material incorporated products in oral application is the poor esthetics because of their black color. Various studies have suggested that the application of other inorganic additives such as sol–gel-based opalescent fillers or chromophoric xerogel pigment particles to achieve the desired esthetic requirements. Another possible application might be the use of carbon nanfiber/ carbon nanotubes -reinforced to improve the fracture toughness.[18]

Silica dioxide nanoparticles reinforced

In the last decade, silica nanoparticles (e.g., available under the trade names Aerosil (Degussa), HDK (Wacker), Cab–O–Sil (Cabot Corp.) have been proposed as nanoscale fillers to enhance dental resins. Among inorganic carriers, silica dioxide is more promising when compared to other inorganic carriers such as apatite, zeolite and phosphate. The unique characteristic of silica dioxide nanoparticles is its porous structure and adsorption properties. Thereby it can improve the rheological behavior, scratch/abrasion resistance, and surface hardness of the final products.[15]

Nano Composite Artificial Teeth

Wear resistance is the most important physical properties of denture teeth. Porcelain denture teeth are most wear resistant, but they are brittle, lack bonding to the denture base, and difficult to polish. Acrylic resin denture teeth are easier to recontour, but it undergoes excessive wear.So nanocomposite denture teeth comes plays a major role by avoiding the consequences of conventional artifical tooth. It comprises of polymethylmethacrylate, and uniformly dispersed nano - sized filler particles. Their advantages wereit can poduce highly polished surface with stain and impact resistant material. It can enhance the surface structure more lively with superior surface hardness and wear resistance.In these nanocomposite artificial teeth, inorganic fillers in nano-dimensions are diffused homogenously without any accumulation in the matrix. Therefore, the smoothness of the surface can be preserved even when the teeth are eroded. Nanocomposite artificial teeth are more durable than acrylic teeth and microfill composite teeth and have a higher resistance to abrasion. Moreover, composite resin artificial teeth containing nanofiller showed superior color which enhanced the esthetics of the denture.The nano-filled composite resins exhibit a chameleon effect whereby they can adjust their color to suit that of their surroundings. This change in shade

is typically similar to the color of the base that is layered with composite resin. The chameleon effect of composite resin has limitations in its color adjustment. Therefore, one shade of composite resin cannot be used to restore every tooth.[19] (FIGURE 3)

Tissue Conditioner

Tissue conditioner used to enhance the recovery of denture bearing tissues from trauma, damage or residual ridge resorption usually caused by ill fitting dentures. With the advent of nanotechnology, silver nanoparticles were commonly incorporated in to tissue conditioner, due to its strong antimicrobial properties. It possess unique interactions with different bacterial and fungal species and it aids in the inhibition of microbial plaque formation and prevent complications such as denture stomatitis.[19]

Impression Materials

Nanofillers are integrated in the vinylsiloxanes, producing a unique addition siloxane impression material that offers better flow, improved hydrophilic properties, hence fewer voids at margin and better model pouring, enhanced detail precision of imoressionmaterial.Ginjupalli et al[20]found that when Silver nanoparticles incorporated in to irreversible hydrocolloid impression it can improve the antimicrobial property.The gelation time of irreversible hydrocolloids was found to increase by increasing the concentration of silver nanoparticles. The increase in gelation time indicates that there was a delay in the formation of calcium alginate gel. The permanent deformation of both irreversible hydrocolloids increased with the incorporation of silver nanoparticles in a dose-dependent manner. However, the increase in the permanent deformation in irreversible hydrocolloid impression materials did not exceed the maximum permanent deformation of 3% as required by the American Dental Association specification. Further investigations on the effect of silver nanoparticles on detail reproduction and biocompatibility are needed. In addition, a detailed investigation on the effect of silver nanoparticle size on the antimicrobial activity and properties of irreversible hydrocolloids is warranted.The pH of the filler had a negative correlation with setting time of PVS. The higher pH resulted in the faster working and setting time.[21](FIGURE 4)

Nano Ceramics

Nanoceramic refers to the ceramic material with nanoscale dimensions in the microstructures phase. Compared with the conventional ceramics, nanoceramics have unique properties, which make it become the hot topics in the study of material science. Firstly, nanoceramics have superplasticity. Ceramic is essentially a kind of brittle material; however, nanoceramic shows good toughness and ductility. As far as the arrangement of atoms in nanoceramics interface is quite confusing, the atoms are very easy to migrate under the conditions of force deformation. Secondly, compared to the conventional ceramics, nanoceramic has the superior mechanical properties, such as strength and hardness increasing significantly. The hardness and strength of many nanoceramics are four to five times higher than those of the traditional materials. For example, at 100◦ C the microhardness of nano-TiO2 ceramics is 13,000 kN/mm^2 , while that of ordinary TiO2 ceramics is lower than 2,000 kN/mm2. Most importantly, toughness of nanoceramics is much higher than that of traditional ceramics. At room temperature, nano-TiO2 ceramic exhibits very high toughness. When compressed to 1/4 of the original length, it was still intact without being broken.Li et aldiscussed about the different physical

properties of nano-ZrO2 ceramic materials from the traditional ones. The hardness of traditional ZrO2 was generally around 1,500, and its fracture toughness was very low, so breakage or crack might easily occur in the processing. However, the hardness of nanozirconia ceramics could reach more than 1,750, increased by about 20%.Not only does its hardness increase, but also the fracture toughness also increased accordingly.[22]Wang et alsuggested that the composite had better toughness with 20% nano-ZrO2, very suitable for dental all ceramic restorations.[23]Persson et al used a sol-gel method to produce glass ceramics in the zirconia-silica system with nanosized grains, which was found to be translucent, with a transmittance of over 70%, and possessed excellent corrosion resistance. It also presented a somewhat lower elastic modulus but higher hardness than the conventional lithium disilicate.[24]

Dental Porcelain

Dental porcelains currently used for ceramic restorations are brittle, and it is sometimesnecessary to correct the fractured or chipped restorations. Mitsunori Uno suggested that by adding Ag nanoparticlesto dental porcelain, it significantly increased the fracture toughness and vickers hardness of the porcelain.[25]Tokushifujieda suggested that by incorporatingnanoparticles of precious metals of silver and platinum in dental porcelain and came to a conclusion that the addition of silver and platinum nanoparticles enhanced the mechanical properties of porcelain. The addition of silver and platinum nanoparticles increased both the Young's modulus and the fracture toughness of dental porcelain. Silver nanoparticles increased the fracture toughness more than platinum.[26]

Nano Adhesives (Nano Solutions)

Nanosolutions can be manufactured by using soluble nanoparticles in to bonding agents. It aids in developing more homogenous and well-mixed adhesive.These type of nanoadhesives will have high bond strength, long shelf-life, good marginal seal, fluoride release, and good stress absorption. According to a study by N. Silikas., there was no decrease in bond strength of dental adhesives after the incorporation of silica or zirconia nanoparticles was obtained.[27]

Dental Cements

when Ag nanoparticles incorporated in toresin composite cement it had a long term inhibitory effect against S. mutans and favorable mechanical properties.By doping the nanosized glass particles in to conventional GIC,it can decrease the setting time and enhances the compression strength and elastic modulus. The main advantages of decreasing setting can aids in ease of handling and manipulation of the material. Addition of nano-apatite or nano-fluoroapatitehasd positive impact on the tensile, compressive and flexural strengths of the set cement after being stored in distilled water for 7 days. According to the recent studies the combined incorporation of HAp and zirconia (HAp/ZrO2) at concentrations of 4% volume to the GIC powder can improve the mechanical properties of the set GIC cement.[28,29]

Maxillofacial Prosthesis

Most of the maxillofacial elastomers perform well initially; however, as time passes deterioration associated with either degradation of mechanical properties or changes in appearance occurs. The degree of success of a maxillofacial prosthesis is determined primarily by the nature of the defect, the

skill of the prosthodontist, and the properties of the material used. The most common problems associated with facial prostheses are loss of esthetics and poor durability, which have been verified by many clinical studies.[30] Color fading is the most frequent response given by patients for disliking their prosthesis. Considering the psychological and social effects on patients of the failure of maxillofacial prostheses, it is necessary to improve the mechanical properties and color stability of elastomers by incorporating nanotechnology.[31]Nanooxide particles are rigid and have a higher shear modulus than the pure silicone elastomer. The results may be attributed to the higher surface energy and chemical reactivity of the particles, allowing them to interact with the silicone elastomer matrix and form a 3-dimensional network.The nanosized material particles provides the optimization of individual material characteristics. Nanosized Silicine dioxide (SiO2), Titaninum dioxide (TiO2), and Zinc oxide (ZnO) were characterized by their small size and large specific area which provided strong interfacial interaction with the organic polymer. Therefore, they can improve the physical and optical properties of the organic polymer, as well as provide resistance to environmental stress-caused cracking and aging.The fact that elastomers have an intrinsic property of losing color with weathering. The incorporation of nano-oxides to maxillofacial silicone elastomer can increase its color stability and also had an opacifying effect.[32]

Dentalimplants

The arrival of nanotechnology gave an ideology for the manipulation of implant surfaces. It is believed that implant surfaces could be improvised by mimicking the surface topography formed by the extracellular matrix (ECM) components of natural tissue. These ECM components are of nanometer scale with typical dimensions of 10–100 nm.[33] Implant surface composition, surface energy, surface roughness and topography were the four aspects which can influence the events taking place at the bone – implant interface. Three type of surface structure are – macro, micro, and nano. Current surface structures are controlled, at best, at the micron level, but the tissue response was mainly dictated by processes controlled at the nanoscale.[34] Surface profiles in the nanometer range could play an important role in the protein adsorption, adhesion of osteoblastic cells and thus the rate of osseointegration could be enhanced. Titanium implants modified by the application of nanostructures aids in the promotion of osteogenic differentiation, and biointegration of these implants into the alveolar bone. Hence, we need the strategies to improve the current metallic dental implants, through surface modifications of the implant either by applying novel coating methods or by patterning the implant's surfaces.[35]

Conclusion

"Less is always more", thus the greatness of this technology lies in its minuteness i.e nano – ness. The advancement in nanotechnology paves way for the future of comprehensive healthcare management. These nanomaterials cannot be seen by the naked eye still it possess powerful capabilities. Similarly it has the potential to bring about significant benefits in terms of improving the oral and overall health. Though the science of nanotechnology may appear as fiction in the present situation, the future holds strong promise for utilizing and maximizing this technology for the benefit of humans.

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Figure

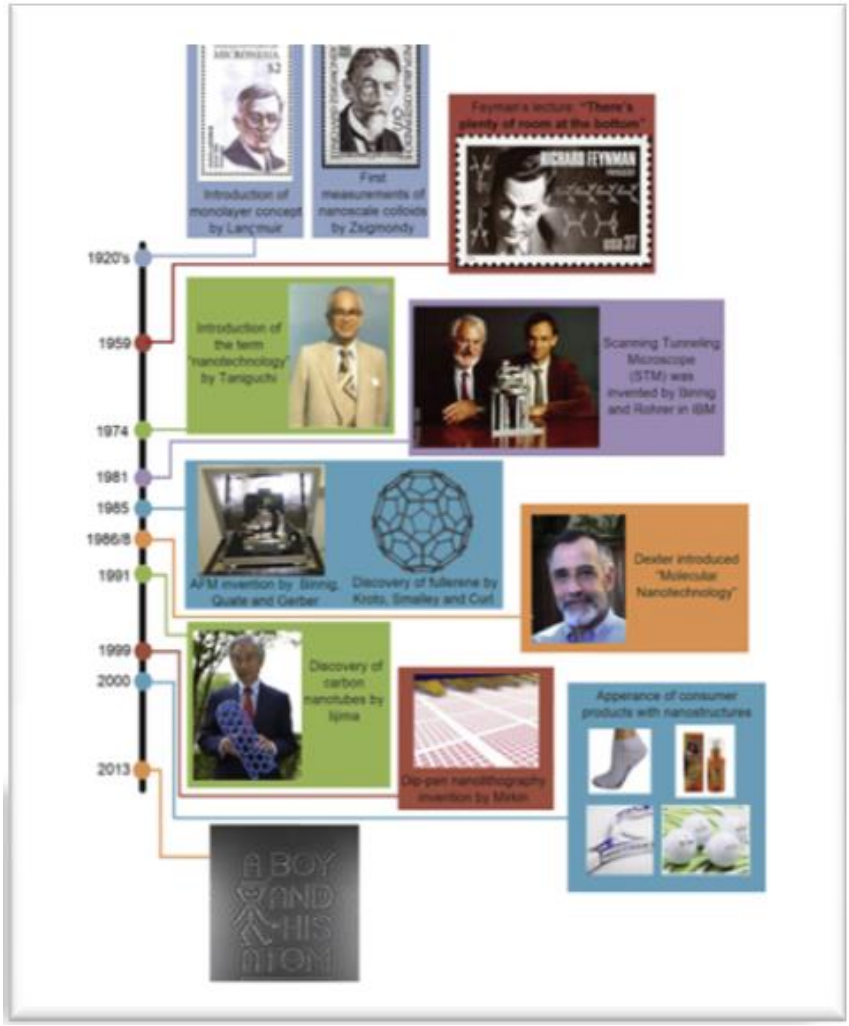

Figure No 1: Historical Evolution of Nanotechnology

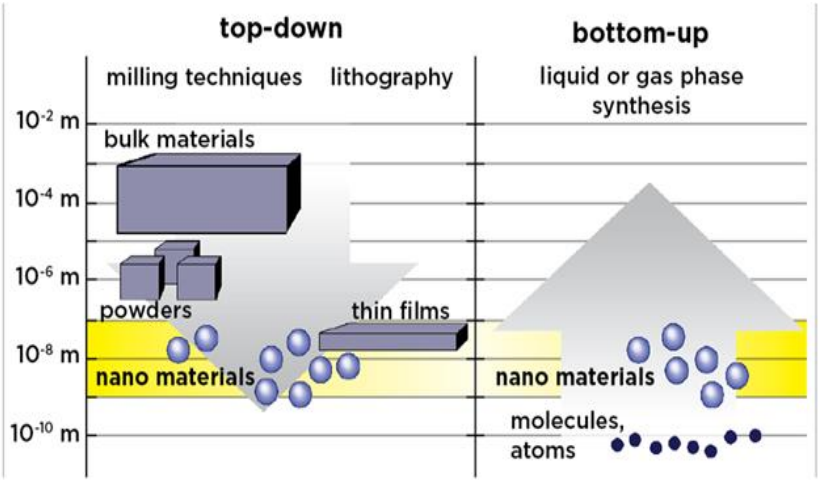

Figure No 2: Top Down and Bottom up Approaches

Figure No 3: Nanocomposite Artificial Teeth

Figure No 4: Polyvinyl Siloxane Impression Material

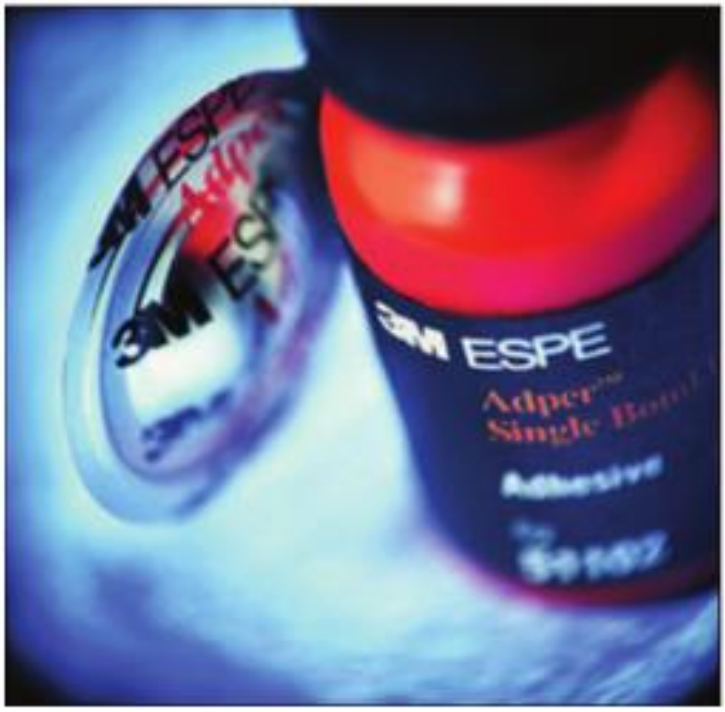

Figure No 5: Nano adhesives